

# Holographic Principle and Quantum Physics

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## Abstract

The concept of holography has lured philosophers of science for decades, and is becoming more and more popular in several front areas of science, e.g. in the physics of black holes. In this paper we try to understand things as if the visible universe were a reading of a lower dimensional hologram generated in hyperspace. We performed the whole process of creating and reading holograms of a point particle in a virtual space by using computer simulations. We claim that the fuzziness in quantum mechanics, in statistical physics and thermodynamics is due to the fact that we do not see the real image of the object, but a holographic projection of it. We found that the projection of a point particle is a de Broglie-type wave. This indicates that holography could be the origin of the wave nature of a particle. We have also noted that one cannot stabilize the noise (or fuzziness) in terms of the integration grid-points of the hologram, it means that one needs to give the grid-points a physical significance. So we further claim that the space is quantized, which supports the basic assumption of quantum gravity. Our study in the paper, although is more qualitative, yet gives a smoking gun hint of a holographic basis of the physical reality.

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## I. INTRODUCTION

The theory of holography was first developed by Hungarian scientist Dennis Gabor around 1947-48 while working to improve the resolution of an electron microscope [1]. The first holograms were of poor quality, but the principle was good. According to the principle of holography, a detailed three dimensional image of an object can be recorded in a two dimensional photographic film and the image can be reproduced back in a three dimensional space. The complex patterned information stored in the film is called 'hologram' (see in Fig. 1). The holograms have a strange feature, unlike the conventional photographic film, once you cut a hologram into pieces each piece is capable of reconstructing the entire image, although with lesser and varying resolutions.

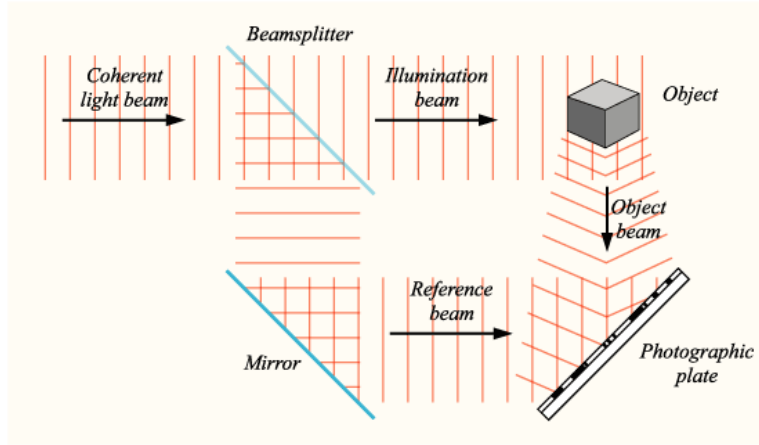


FIG. 1: Image taken from [2]

The holographic concept has lured philosophers of science for decades [3, 4], and is becoming more and more popular in several front areas of science; attracting the researchers of cosmology, astrophysics, extra-dimensions, string theory, nuclear and particle physics and neurology [5] etc... One can find hundreds of papers in the internet discussing the relevance of holography in these fields. Some articles claim that our visible and highly complex universe is actually a hologram of a higher dimensional but simpler reality. The holographic principle is now widely being used to relate seemingly unrelated things, like quantum mechanics and gravity [6]. Theoretical results about black holes suggest that the universe could be like a gigantic hologram [7]. So our seemingly three-dimensional universe could be completely equivalent to alternative quantum fields and physical laws "painted" on a distant,

vast surface.

On the same lines, in our paper we try to understand things as if the visible universe were a reading of a lower dimensional hologram generated in hyperspace. Our procedure goes as follows. To start with, we perform the whole process of creating and reading holograms in a virtual space by using computer simulations. For simplicity we consider a point object with no geometrical size at rest and at uniform motion. First, we create the hologram of the point object using a reference beam and an object beam. Second, we read the created hologram by illuminating it with a suitable reference beam.

Ideally, the reconstruction procedure should give back the original point object in our normal physical space, but we know that no optical procedure gives a strictly point-like image of a point-like object. Assuming holography as the basis of physical reality, we claim that some dynamics seen in the observable world (such as fuzziness in quantum mechanics, in statistical physics and thermodynamics) can come from such a procedure. This fuzziness is basically a noise that has a dynamics of its own. In this work we will try to understand this in detail.

In the first section II we describe the creation and reading of hologram in usual space and hyperspace. In the second section III we study the image created by the holographic mapping of a single stationary point, and then reading the hologram. In the third IV section we repeat this procedure for a linearly and uniformly moving point. Both III and IV will suggest that the image of a point-like particle is a wave that is described by a de Broglie-type of relation [8]. This supports our assumption of a holographic base of physical reality. We have also noted that one cannot stabilize the noise (or fuzziness) in terms of the integration grid-points of the hologram screen, it means that one needs to give the grid-points a physical significance. So we further claim that the space is quantized, which concurs with the basic assumption of quantum gravity.

In section VI we present the discussion and conclusions.

## **II. HOLOGRAPHIC MAPPING IN HIGHER DIMENSION AND READING OF THE HOLOGRAM**

In this section we first describe the creation of holograms in usual space and hyperspace. We create a two-dimensional hologram (II A). Next, we describe the reconstruction of the

hologram in the usual three-dimensional space (IIB). It must be noted that the holograms are not necessarily created by light, but can be formed in the presence of any wave action. In principle they can be created and read with different kind of waves, such as scalar, vector (electromagnetic, acoustic), tensor (gravitational), and the calculation principles are basically the same [9].

Since the motivation is to understand the usual three-dimensional world reality as a holographic projection of some higher dimensional reality, we realize that we need atleast five dimensions (3+2) to create the usual three-dimensional image (the objects we perceive through our senses). The extra two dimensions are required for the reference and object beams to propagate, since we do not see them.

### A. Creating hologram

The hologram itself is the picture of the interference pattern of a beam that comes from an object we want to map and a reference beam. For simplicity we assume a scalar beam, but the result is the same for other waves as well [9], since, according to this reference, the interference pattern does not depend on the spinorial structure of the wave (like scalar, vector, etc.). The hologram as well as its reading are interference patterns, so this independence is understandable. The hologram is produced, as seen in Fig. 1 and 2, by splitting a single beam into two pieces: one is shed on the object and the other directly on the photographic plaque. In our case we assume a five-dimensional space with the holographic screen lying on the  $(x, y)$  plane by construction. We take a beam that hits the object propagates in the fifth dimension and a reference beam that propagates in the  $(y, x_4)$  plane. And there is an angle  $\psi_r$  between the beam itself and the  $x_4$  axis. We didn't take it in the  $(x_4, x_5)$  plane because in such case the reference wave that hits the screen remains always normal to it. We assume that the phase of the reference beam is  $\phi_{r_i}$  at the point  $(y, x_4) = (0, 0)$ . The wavelength of the radiation is  $\lambda = 2\pi/k$  and  $k$  is the wave number. Therefore the phase of the reference beam at an arbitrary site is  $\phi_r = \phi_{r_i} + kx_4 \cos(\psi_r) - ky \sin(\psi_r)$ . On the screen  $x_4 = 0$ , so  $\phi_r = \phi_{r_i} - ky \sin(\psi_r)$ .

This wave has an amplitude  $E_{r0}$ , so its value is

$$E_r = E_{r0} \exp[i(\phi_{r_i} - ky \sin(\psi_r))]. \quad (1)$$

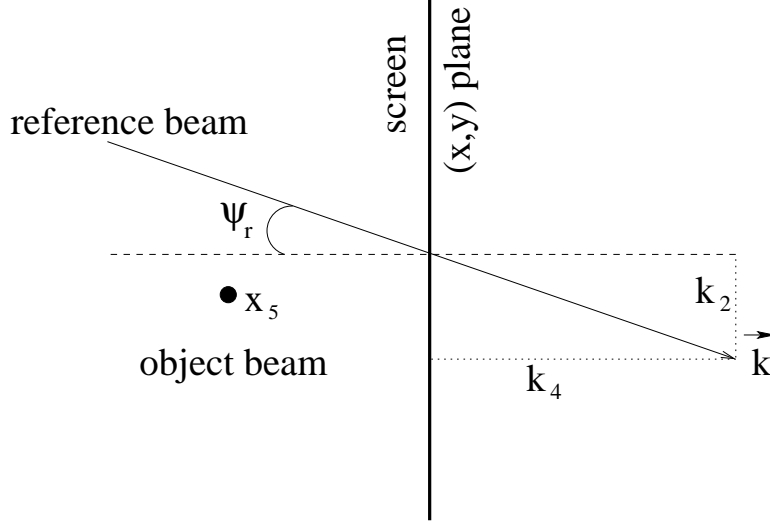


FIG. 2: A schematic diagram showing the reference beam propagation in  $(y, x_4)$  plane into the photographic film on  $(x, y)$  plane. The dot represents the object beam propagating in the fifth dimension.

Likewise the phase of the beam that is reflected from the object is  $k(x_5 + r)$ , where  $r$  is the distance between the object and an arbitrary point on the screen where we compute the phase. The reflected wave therefore is

$$E_o = E_{o0} e^{i(\phi_{r_o} + k(x_5 + r))} / r^{(d-1)/2}, \quad (2)$$

where  $E_{o0}$  is a constant proportional to the square root of the surface of our object, the square root of its reflectivity ( $R$ ) and the original field strength of the object beam. Here  $d$  is the dimensionality of our space. However,  $\phi_{r_o}$  is the initial phase of the wave which hits the object. These two fields can be added together and squared, and then we have the interference picture that is the hologram.

How do we determine  $E_{o0}$ ? The energy that hits the object is  $S_d E_{o0}^2 / 2$ , where  $S_d$  is the “cross section” of the object in  $d$  dimensions. Thus, in two dimensions it is  $2r_o$  (where  $r_o$  is the radius of the “spherical” object) in three dimensions it is  $\pi r_o^2$ , and by generalization, for  $d$  dimensions it is  $V_{d-1}$ , where  $V_d$  is the volume of the  $d$  dimensional sphere. The energy that comes out ( $I_o$ ) is  $R^2$  times the one that goes in ( $I_i$ ). The energy is spread out on the whole “solid angle”  $\Omega_d$ .  $\Omega_d$  is determined from the following identities:

$$\begin{aligned}\int d^d x \exp(-ax^2) &= \Omega_d \int_0^\infty \exp(-ar^2) r^{d-1} dr \\ \int d^d x \exp(-ax^2) &= \left(\frac{\pi}{a}\right)^{d/2},\end{aligned}\tag{3}$$

and it is found to be

$$\Omega_d = \frac{2\pi^{d/2}}{\Gamma(\frac{d}{2})},\tag{4}$$

where  $\Gamma$  is the Euler function. The  $d$  dimensional volume is  $\Omega_d r^d/d$ . The energies going in and coming out are given as  $I_o = \Omega_d r^{d-1} E_o^2/2$  and  $I_i = S_d E_i^2/2$ , respectively. As discussed before they are related as

$$I_o = R^2 I_i,$$

such that

$$|E_o| = |E_i| \sqrt{\frac{S_d R^2}{r^{d+1}}},\tag{5}$$

where  $E_i$  and  $E_o$  are in-going and out-going waves, respectively. In our calculations  $E_i$  and  $S_d$  are the numerical inputs, which we choose so as to get the clear wave pattern with minimum noise.

## B. Reading hologram

The hologram is read once one sheds a wave on it and, the direction and the frequency of this beam should be same as those of the reference beam that was used to create it. In order to read hologram we will disgress from the way we created it. We will read it in 4D space, since we don't need object beam (the fifth dimension), however our reading beam is the same as the original reference beam that created the hologram.

In order to determine the image generated by a hologram when we shed some wave onto it, one must know the reflected fields at any given point. The square of those fields is

proportional to the intensity of the reflected radiation, and knowing that, we can have an analytical description of the generated image. If some wave is reflected from a surface (such as a hologram), we can compute the reflected fields on the surface and we can examine how those fields propagate. First we consider how static fields are determined from known boundary conditions and after that we extend the calculation for wave fields.

The Green function  $G(\vec{r})$  of a static field is defined as:

$$\nabla^2 G(\vec{r}) = -\delta(\vec{r}). \quad (6)$$

The field at any given point can be calculated as:

$$\varphi(\vec{r}') = \int_V d^3\vec{r} \varphi(\vec{r}) \delta(\vec{r}, \vec{r}') = - \int_V d^3\vec{r} \varphi(\vec{r}) \nabla^2 G(\vec{r}, \vec{r}'), \quad (7)$$

where the derivative  $\nabla$  is related to the variable  $\vec{r}$ . Here  $\vec{r}$  and  $\vec{r}'$  are the distance vectors of the fields  $\varphi$  on the screen and on a given point.

After applying the following identities:

$$\begin{aligned} \varphi(\vec{r}) \nabla^2 G(\vec{r}, \vec{r}') &= \vec{\nabla} \left[ \varphi(\vec{r}) \vec{\nabla} G(\vec{r}, \vec{r}') \right] - (\vec{\nabla} G(\vec{r}, \vec{r}')) (\vec{\nabla} \varphi(\vec{r})), \\ (\vec{\nabla} G(\vec{r}, \vec{r}')) (\vec{\nabla} \varphi(\vec{r})) &= \vec{\nabla} (G(\vec{r}, \vec{r}') \nabla^2 \varphi(\vec{r})), \end{aligned} \quad (8)$$

and making use of the Laplace equation:

$$\nabla^2 \varphi(\vec{r}) = -\rho(\vec{r}), \quad (9)$$

the field in any point can be calculated as

$$\varphi(\vec{r}') = \int_V d^3\vec{r} G(\vec{r}, \vec{r}') \rho(\vec{r}) + \int_S d^2\vec{r} G(\vec{r}, \vec{r}') \nabla_n \varphi(\vec{r}) - \int_S d^2\vec{r} \varphi(\vec{r}) \nabla_n G(\vec{r}, \vec{r}'), \quad (10)$$

where  $\nabla_n$  is the component of the derivative that is perpendicular to the surface.

The first term refers to the sources and we assume that there are no sources in the part of space we examine. The other two terms are the so-called surface terms. Whenever the first surface term vanishes (and the Green's function must be chosen accordingly, so that it vanishes on the surface) we must know the value of the field on the surface, and we are said to use the Dirichlet conditions. If we know only the derivatives of the fields on the surface, we must require that the normal derivative of the Green's function vanishes on the surface,

we are said to make use of a Neumann Green's function. Note that any of these conditions can be met at any time (although not both at the same time) because Eq. (6) does not completely fix the Green's function, so we might add any term whose Laplacian is zero (in the region of space we are interested in) in such a way that the new Green's function satisfies either one of the two conditions. Because we can calculate the fields at the surface, we will use a Dirichlet Green's function, so our field at any given point is expressed as follows:

$$\varphi(\vec{r}') = - \int_S d^2\vec{r} \varphi(\vec{r}) \nabla_n G(\vec{r}, \vec{r}'). \quad (11)$$

From the image solution for the auxiliary electrostatic problem, the Green function for Dirichlet conditions can be calculated. We need to know the Dirichlet Green's function on a plane. First we define some new variables  $\vec{r}_1$  and  $\vec{r}_2$  as  $\vec{r}_{1,2} = (x-x')\vec{e}_1 + (y-y')\vec{e}_2 + (z \mp z')\vec{e}_3$ , (in terms of our orthonormal basis  $\vec{e}_1, \vec{e}_2, \vec{e}_3$ ),  $r_{1,2} = \sqrt{(\vec{r}_{1,2} \cdot \vec{r}_{1,2})}$ . In these terms, the Dirichlet Green's function is given in [10] as:

$$\tilde{G}(\vec{r}, \vec{r}') = \frac{1}{4\pi} \left( \frac{1}{r_1} - \frac{1}{r_2} \right). \quad (12)$$

If instead of static field we have wave fields, this Green's function is replaced with

$$G(\vec{r}, \vec{r}'; t) = \frac{1}{4\pi} \left( \frac{\delta(t - r_1/c)}{r_1} - \frac{\delta(t - r_2/c)}{r_2} \right), \quad (13)$$

where  $c$  is the phase velocity of our wave. Since we consider only one frequency ( $\omega$ ), we only need the Fourier transform of this Green's function, which is:

$$G(\vec{r}, \vec{r}'; \omega) = \frac{1}{4\pi} \left( \frac{\exp(-ikr_1)}{r_1} - \frac{\exp(-ikr_2)}{r_2} \right), \quad (14)$$

with  $k = \omega/c$  as the wave number. We substitute this result into Eq. (11). How can we justify this substitution, since Eq. (11) has been derived based on the assumption that the fields are static? We know that if there is a wave field, Eq. (9) is replaced with

$$\left( \nabla^2 - \frac{\partial^2}{\partial t^2} \right) \varphi(\vec{r}) = -\rho(\vec{r}). \quad (15)$$

If we only consider one frequency and retarded waves only, our field can be expressed as

$$\varphi(\vec{r}, t) = \varphi(\vec{r}, t = 0) \exp[-i\omega(t - l/c)], \quad (16)$$

where  $l$  is the distance between the source and observer. Substituting this into Eq. (15) and dividing the resulting equation by  $\exp(-i\omega(t - l/c))$  we obtain Eq. (6). So if we work with



the time Fourier transforms of the wave fields and Green's functions and assume only one frequency, we are able to make use of the static formulation of the problem using the Fourier transform of the Green's function we have just given in Eq. (14). The normal derivative of this Green's function on the surface defined by the hologram is:

$$\nabla_n G(\vec{r}, \vec{r}') = -\frac{\partial}{\partial z} G(\vec{r}, \vec{r}')|_{z=0}, \quad (17)$$

which, because we assume much smaller wave lengths than the distances  $r_{1,2}$ , we approximate as:

$$\begin{aligned} \nabla_n G(\vec{r}, \vec{r}') &= \frac{1}{4\pi}(-2ik) \left( \frac{(z - z') \exp(-ikr_1)}{r_1} - \frac{(z + z') \exp(-ikr_2)}{r_2} \right) |_{z=0} \\ &= \frac{ikz'}{2\pi} \frac{\exp(-ikr')}{r'}, \end{aligned} \quad (18)$$

and this we are able to substitute into Eq. (11). If the dimensionality were different (but greater than three), Eq. (19) would be modified in the following way:

$$\nabla_n G(\vec{r}, \vec{r}') = \beta k z' \frac{\exp(-ikr')}{r'^{d-2}}, \quad (19)$$

where  $d$  is the dimensionality of the space and  $\beta$  is an irrelevant constant we do not even bother to give. Whenever we are reading the hologram, the only relevant difference that comes from this formula is the phase given by the exponential, all the rest would be irrelevant. Therefore it does not matter whether we read our hologram in a three or four dimensional space. This we also confirmed by our numerical calculations.

Now the only thing missing from the picture is the reflected field at any given point of the hologram. The phase and amplitude of the reflected wave depends on the phase and amplitude of the reading wave:

$$\vec{E}_{rf} = |R_h| \vec{E}_{rd}, \quad (20)$$

where  $\vec{E}_{rf}$  is the reflected wave,  $R_h$  is the reflectivity of the hologram (it is the hologram data file generated in the previous step) and  $\vec{E}_{rd}$  is the reading wave (exactly same as the reference beam in eq. 1).

$$\vec{E}_{rd} = \hat{x} E_{r0} \exp(-iky \sin(\psi_r) + i\phi_{r_i}), \quad (21)$$

where  $E_{r0}$  is its amplitude,  $\phi_{r_i}$  is its phase at the point  $(y, x_4) = (0, 0)$  and  $\psi_r$  is its angle of incidence. By construction, the reading beam is the original reference wave (2) that propagates in the  $(y, x_4)$  plane. There is a phase shift of  $\pi$  after the reflection.

We incorporate Eqs. (11), (19), (20) and (21) in a numerical code to compute the reflected fields (and therefore the intensities) at any given point of the space. Therefore, we obtained the image from the hologram we were reading.

### III. IMAGES OF A STATIONARY POINT

In this section we describe the image created by reading a hologram of a stationary point. Like any optical procedure, this process too will give us a blurry picture instead of a single point. We will study the dynamics of this blurriness and try to read some physics into it.

The arguments of this section are not nearly as rigorous as those of the next one, they are actually some kind of hand-waving arguments that only suggest some possible conclusions rather than prove any. However, this is indicative for the direction of the next section that is going to be somewhat more rigorous than the present one.

We consider a point-like object in a five-dimensional space. Why do we need five dimensions? As said before, we consider a reference beam and an object beam that are not visible, therefore we need some extra dimensions. Since these two beams should propagate in different directions, the number of the extra dimensions is two. We then numerically create its hologram that we will read in our usual three-dimensional space, but the beam shed on our hologram will not be part of our three-dimensional space, since we cannot see them.

Now we assume that the point-like object is separated by the center of our rectangular screen (whose picture is the actual hologram) by a distance  $D$ , the sides of the screen are equal and their size is  $d$ , and that the line of separation is perpendicular to the screen. For the numerical integration that is involved in the reading of the hologram, we divided the screen into  $40^2$  equal regions.

First, we consider the case when the image of our point resembles a Gaussian distribution. This is the case, when, for example  $D = 5$  units,  $d = 15$  units and  $\lambda = 0.5$  units which we

$D$	5	7.5	10	12
$\Gamma$	0.83	0.64	0.40	0.30

TABLE I: *Empirical study (particle at rest) of the parameters:  $\Gamma$  and  $D$*

$D$	50	62.5	75	87.5	100
$\Lambda$	1.0	1.3	1.6	1.9	2.2

TABLE II: *Empirical study (particle at rest) of the parameters:  $\Lambda$  and  $D$*

show also graphically in Fig. 3.

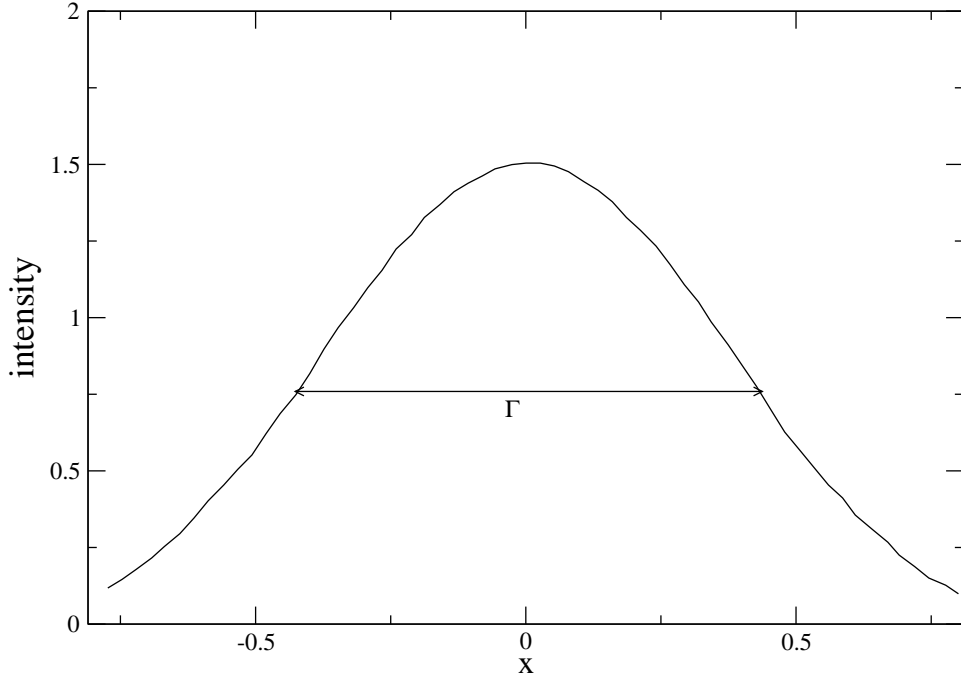


FIG. 3: The image for  $D = 5$  units,  $d = 15$  units and  $\lambda = 0.5$  units. We found that  $\Gamma = 0.83$  units.

$\Gamma$  is the width of the Gaussian curve. From table I it appears that  $\Gamma \sim 1/D$ . Gaussian curves are obtained if  $\lambda \ll d$ ,  $\lambda \ll D$  and  $d > D$ .

Another feature we obtained from our procedure is a wave like pattern. This is the case, if  $D = 100$  units,  $d = 0.4$  units and  $\lambda = 5 \times 10^{-3}$  units. Here  $\Lambda$  is the wavelength of the

pattern obtained. The specimen figure is shown in Fig. 4. The table II shows that  $\Lambda \sim D$ .

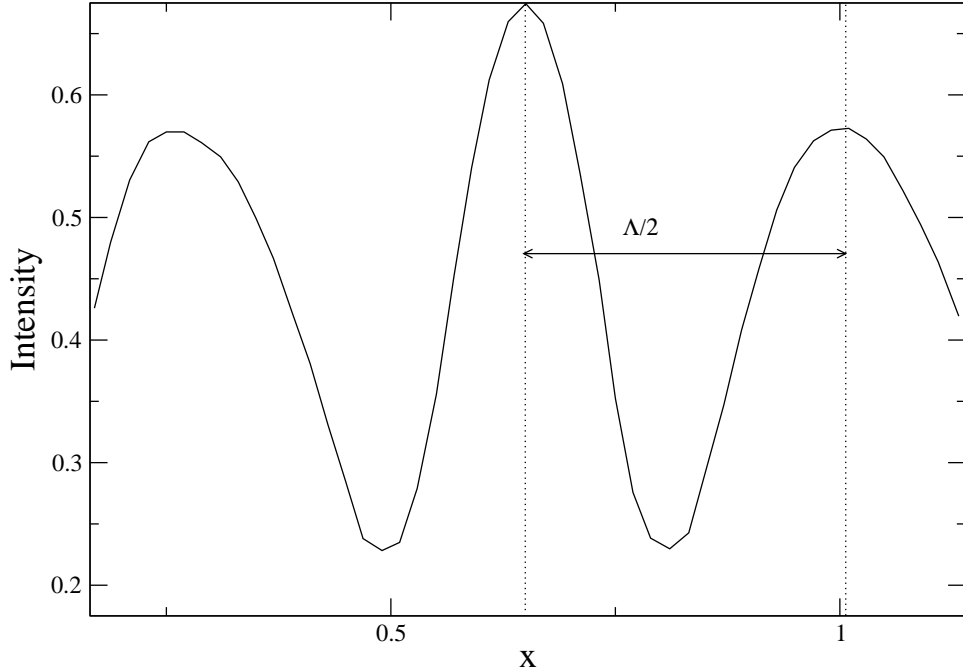


FIG. 4: Holographic projection of a point particle at rest. Here  $D = 75$  units,  $d = 0.4$  units and  $\lambda = 0.005$  units.

Now here comes our hand-waving and very qualitative argument. From thermal physics we know that the width of the Gaussian distribution is proportional to the root mean square of the momentum,  $p_{rms}$ . Therefore one can say that  $\Lambda \sim D \sim 1/\sqrt{p^2}$ , so  $\Lambda \sim 1/p_{rms}$ . This is a de Broglie type relation, where the wavelength is inversely proportional with the momentum of the particle. In our calculation we encountered a difficulty, however: the result cannot be stabilized in terms of the gridpoints. For a different number of gridpoints we are able to get the same patterns and the same proportionality relations, but the graphs are different. This is understandable since the signal we investigate is basically a noise. The only way out is to suppose that space is quantized. Therefore not only statistical physics and quantum physics may be dependent, but quantization of space could also be related to these two.

#### IV. IMAGES OF A MOVING POINT

A more elegant and compelling argument is the holographic mapping of a moving particle. We imagine that the hologram is taken during a finite interval of time; meaning that in every instant there is a snapshot, and these photographs are superposed, the resultant being the final hologram. The hologram then is read as we described in the previous sections. The emerging pattern in this situation is again a wave (see Fig. 5). The only difference from the former calculations is that on the RHS of Eq. (2) the exponent  $\phi_{r0} + kr$ , which is the eikonal function of the wave field is replaced with the full eikonal. We do this because the moving point is also a dynamical system. Therefore this exponent becomes  $\phi_{r0} + kr + c\vec{P} \cdot \vec{\mathcal{R}}$ , where  $\vec{P}$  is the momentum of the particle and  $\vec{\mathcal{R}}$  is its position vector. The constant  $c$  was included to match the dimensionalities, but in the numerical calculations we assume that

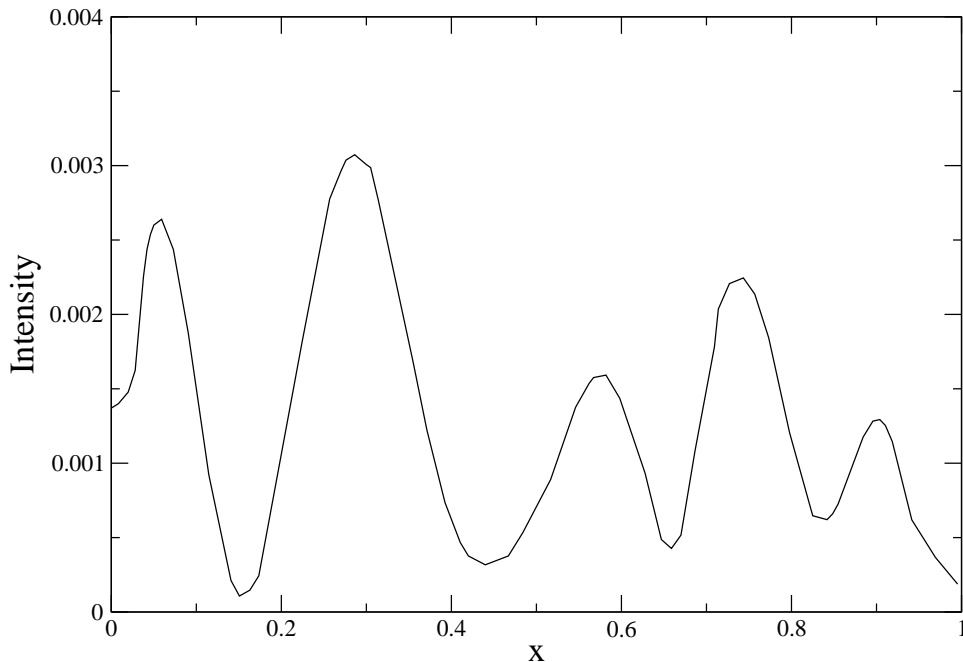


FIG. 5: Holographic projection of a moving point particle. Here  $D = 40$  units,  $d = 1.5$  units and  $\lambda = 0.005$  units.

$c = 1$ . Here we used a non-relativistic approximation,  $\vec{P} = m\vec{v}$ , where  $m$  is the mass of the particle and  $v$  is its velocity. We assumed a mass of 3200 units, than we repeated our calculations by doubling and halving it, and by using two other masses in this domain.

$P \times 10^{-4}$	2	3	4	5
$\Lambda$	0.40	0.27	0.22	0.16

TABLE III: *Empirical study (moving particle) of the parameters:  $\Lambda$  and  $P$*

This way we proved that the wavelength depends on the momentum, but not on the mass or velocity. We found that the wavelength  $\Lambda$  of this wave depends on the momentum  $P$ . We considered  $D = 40$  units,  $d = 1.5$  units and  $\lambda = 5 \times 10^{-3}$  units. We divided the screen into  $70^2$  equal squares in order to do the numerical integration involved in reading the hologram.

This calculation indeed suggests that within the limit of our errors the the Broglie relation,  $\Lambda \sim 1/P$  is satisfied. The only thing remaining to be clarified is the origin of the spinorial structure for this wave. We propose that it has to be the same as that of the mapping wave.

## V. FURTHER CONSIDERATIONS

We could ask the question: is there a more general argument that tells us that quantum physics should come from an other principle? In other way is there another argument to further justify, to strengthen our former reasoning of associating waves with spinor structure to particles? The answer is positive, and we give this reasoning here, but its only disadvantage is that it is completely general, does not even give us the de Broglie relation nor does it tell us how to associate waves to particles, as we did in the former paragraphs.

Variational principles can be applied to a wide variety of systems. These systems either have a finite degrees of freedom or infinite degrees of freedom. Another possibility does not exist. The former case is the mechanics of a finite number of points and the latter case is basically a field theory. In this section we discuss why the case of the point mechanics has difficulties in the relativistic context, and propose a solution how this complication can be solved.

For a point like particle, in the non-relativistic context, the variational principle reads:

$$\int dt \left( m \frac{v^2}{2} - V \right) = minimum. \quad (22)$$

Here  $m$  is the particle mass,  $v$  is its velocity, and  $V$  is its potential energy. This variational principle leads to the conservation of  $H = \frac{1}{2}mv^2 + V$ , which happens to be the energy. In relativistic mechanics, if we neglect interactions, there are two variational principles for a

point-like particle. The first one is not manifestly covariant

$$- mc^2 \int \sqrt{1 - \frac{v^2}{c^2}} dt = \textit{minimum} . \quad (23)$$

The function  $H = \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}}$  is the corresponding conserved quantity that is the energy as it was in the previous case. The only problem is that the formalism is not manifestly covariant. The manifestly covariant principle reads:

$$- m \int d\tau u^2 = \textit{minimum} . \quad (24)$$

But here  $u$  stands for the four-velocity and  $\tau$  for the proper time. However, the conserved Hamiltonian associated to this action is zero. So, it is impossible to introduce for a point like particle a relativistic, manifestly covariant action principle that gives the right Hamiltonian. On the other hand, this is possible for fields.

How do we solve then the issue of point-like particles? One way would be eliminating them completely, but that would be eliminating a part of reality, since such particles exist. An other way would be eliminating relativity or the need for a manifestly covariant description, which has the same disadvantage of ignoring reality. The only remaining possibility would be associating to any such a particle another system which does have a relativistic, manifestly covariant description, and that could be only a field. Any field is a function that depends on the spacetime, and that can be decomposed in plane waves, therefore it is a wave. But the assertion that to every particle there is a corresponding wave is the basic assumption of quantum physics. Therefore quantum physics, or at least a part of it, seems to follow from relativity.

## VI. DISCUSSION & CONCLUSIONS

Quantum theory predicted that regardless of the distance between the particles, their polarizations would always be the same. The act of measuring one would force the polarization of the other. This shows a spooky exchange of informations between the two particles, which violates the principle of relativity. Alain Aspect's experiment [11] at the university of Paris has shown that under certain circumstances subatomic particles such as electrons do communicate instantaneously. It doesn't matter whether they are 1 meter or 1 billion

kilometers apart. This result is hard to digest, however a British physicist David Bohm [12] claimed Aspect's findings imply that objective reality doesn't exist. Despite its apparent solidity the universe at heart is phantasm, a gigantic and splendidly detailed hologram.

In other words, the separateness of things is but an illusion, and all things are actually part of the same unbroken continuum. We see the separateness of things because we see the partial reality. He gave a nice analogy of a fish in an aquarium, which is seen through two TV cameras, focused on at different angles, on two respective screens. It appears that there are two fishes, but simultaneously communicating, which is because either image of the fish contains only a partial information, i.e. a lower dimensional reality.

There are speculations that our universe could be a hologram of higher dimensional reality on the 4-D surface at its periphery. Theoretical results about black holes suggests that the universe could be like a gigantic hologram [7]. So our innate perception that the world is 3+1 dimensional reality could be just an illusion, and our seemingly three dimensional universe can be a projection of a bigger reality.

In terms of informations the holographic principle holds that the maximum entropy or information content of any region of space is defined not by its 'volume', but by its 'surface area'. According to John A. Wheeler of Princeton University the physical world is made of information, with energy and matter as incidentals. Holography may provide a guiding torch to discover a better theory or 'Theory Of Everything'. So the final theory might be concerned not with fields, not even with spacetime, but rather with information exchange among physical processes [7].

The revolution in the Holographic Principle is now a major focus of attention in many area of science e.g. gravitational research, quantum field theory and elementary particle physics. A popular account of holography can be found in [6, 13, 14]. For a more technical discussion see [15].

In this work we discovered that the holographic projection of a point particle is a wave like structure. We have also noted that for a fixed distance (D) of particle from the screen of hologram and fixed wavelength of the reference & object beam there exists a relation between momentum and wavelength of the wave pattern associated with the particle. This relation is similar to the famous de Broglie-type relation:  $\Lambda \sim 1/p_{rms}$ .

Now, we conjecture here that since the relation (or the proportionality) between wavelength and momentum is similar to that of the de Broglie relation, it could be the the



wave-pattern which we associate with all the particles in quantum mechanics. If this is so, we then understand the origin of the wave like nature of quantum particles. This will also show a holographic basis for the existence of this intire physical world. Whatever we see around is a holographic projection of a bigger reality. In other words, that a point particle is not seen as a point, but a fuzzy Gaussian wave that has been observed in quantum mechanical experiments. We can dare to say that the holographic projection wave of the point particle is essentially the so-called de Broglie wave.

We also noted that there is a need to give a physical significance to the grid points of the hologram screen, which prove another assumption of quantum gravity: the space is quantised. We want to go one step further and argue that for the macro particles (classical objects) this fuzziness, noise and wave pattern due to holographic projection are weak and so hard to observe. To test this argument one should bear in mind that now each point of the particle is a source of object wave which will interfere with the reference wave and with themselves. In our investigation, we got an impression [16] that although the computation is much more complicated, but the final reconstructed image of the object go sharper as the size of the test object grows up. Such that for the classical objects the fuzziness due to the holographic process will almost disappear and we can see only the physical size and shape of the particle.

As said before the relation  $\Lambda \sim 1/P$  and the wave pattern we found as a holographic projection of a point particle exist only in certain domains of the parameters that we used. It would be interesting to investigate the domains of these parameters with some boundary conditions e.g.  $\lambda \ll d$ ,  $\lambda \ll D$ ,  $\lambda \ll 1/N$ ,  $d \ll D$  and  $\Lambda > d/N$ . Even in the real world there is a domain of validity for every physical theory. For example, quantum mechanics and field theory are valid if the calculated de Broglie wavelength is much bigger than the planck scale, which can be perceived as the minimal disatnce between two points in the quantized space-time continuum. And likewise, this wavelength must be much smaller than the astronomical distances where general relativity sets in. In our next work we want to investigate the validity domain of our conclusions if and whether or not this domain coincides with the domain dictated by the former criteria [16].

## VII. ACKNOWLEDGMENTS

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- [1] Collier, R., Burckhardt, C., Lin, L., “Optical Holography,” 1971, Academic Press, Inc., New York.
- [2] <http://en.wikipedia.org/wiki/Holography>.
- [3] Bohm, D., “Quantum Theory as an Indication of a New Order in Physics—Implicate and Explicate Order in Physical Law,” PHYSICS (GB), 3.2 (June 1973), pp. 139-168.
- [4] Talbot, M., “The Holographic Universe” 1991, HarperCollins Publishers, Inc., New York.
- [5] Pribram, K., “The neurophysiology of remembering”, Scientific American, 220:75, 1969.
- [6] Susskind, L. and Lindesay, J., “Black Holes, Information and the String Theory Revolution. The Holographic Universe”, World Scientific, December 2004.
- [7] Jacob D. Bekenstein, “Information in the Holographic Universe,” August 2003; Scientific American Magazine.
- [8] Luis de-Broglie, Phil. Mag. 46 (1924) 446.
- [9] Max Born, Emil Wolf, Principles of Optics, 1975, Pergamon Press.
- [10] Leonard Eyges, “The Classical Electromagnetic Field,” 1980, Dover Publications, Inc. New York.
- [11] Aspect, A., Dalibard, Roger, G., “Experimental test of Bell’s inequalities using time-varying analyzers”, Physical Review Letters 49, 1804 (20 Dec 1982).
- [12] Bohm, D., “Hidden variables and the implicate order.” In Quantum Implications, eds. B. Hiley and F. Peat. London: Routledge and Kegan Paul (1987).
- [13] Susskind, L., Sci. Am. 276 (1997) 52; J. Maths. Phys. 36 (1995).
- [14] Taubes, G., Science 285, (1999) 512.
- [15] t’ Hooft G., “Dimenssional reduction in quantum gravity” Slamfest 1993, p 284; gr-qc/9310026.
- [16] Zoltan Batiz and Bhag C. Chauhan, in preparation.